

# (12) UK Patent Application (19) GB (11) 2 368 400 (13) A

(43) Date of A Publication 01.05.2002

(21) Application No 0116041.5

(22) Date of Filing 29.06.2001

(30) Priority Data

(31) 12206756

(32) 07.07.2000

(33) JP

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(51) INT CL<sup>7</sup>

G01P 21/00

(52) UK CL (Edition T )

G1N NAHK N7Q

(56) Documents Cited

JP 630132171 A

JP 100048251 A

JP 040313062 A

US 4337516 A

(58) Field of Search

UK CL (Edition T ) G1N NACA NAHK

INT CL<sup>7</sup> G01D 3/08 , G01P 15/00 15/03 15/08 15/13  
21/00

ONLINE: EPODOC, WPI, PAJ

(54) Abstract Title

**Acceleration sensor fault detector**

(57) A fault in an acceleration sensor or accelerometer 11, 12, 13 caused by the sensing weight in the sensor becoming fixed or stuck is detected by software. When the vehicle is running the sensor always outputs small signals due to the vibration of the vehicle. If the output of the sensor is less than a predetermined threshold over several sampling periods then a fault is indicated 3. Also described are systems for estimating lateral acceleration based on differentiation of wheel rotation data and yaw rate based on the same wheel data and on steering wheel angle data  $\alpha$ . These estimates are compared to outputs measured by a lateral acceleration sensor 11 and a yaw rate sensor 13. If the difference between the estimated and measured values is greater than a predetermined threshold then an error signal is generated 3.

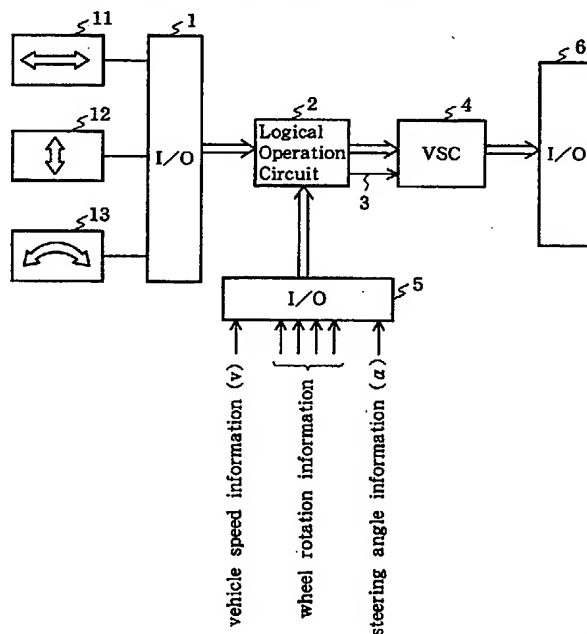


FIG.1

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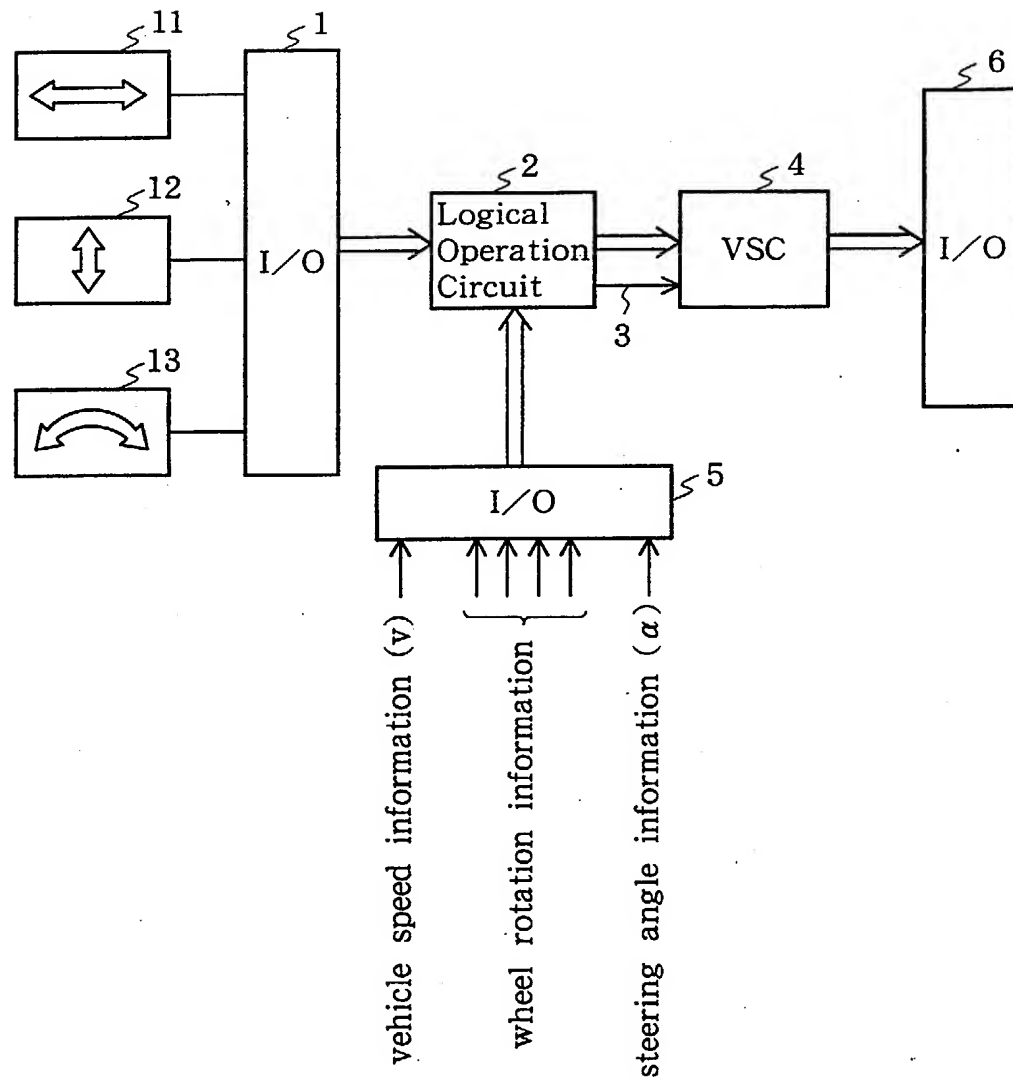


FIG.1

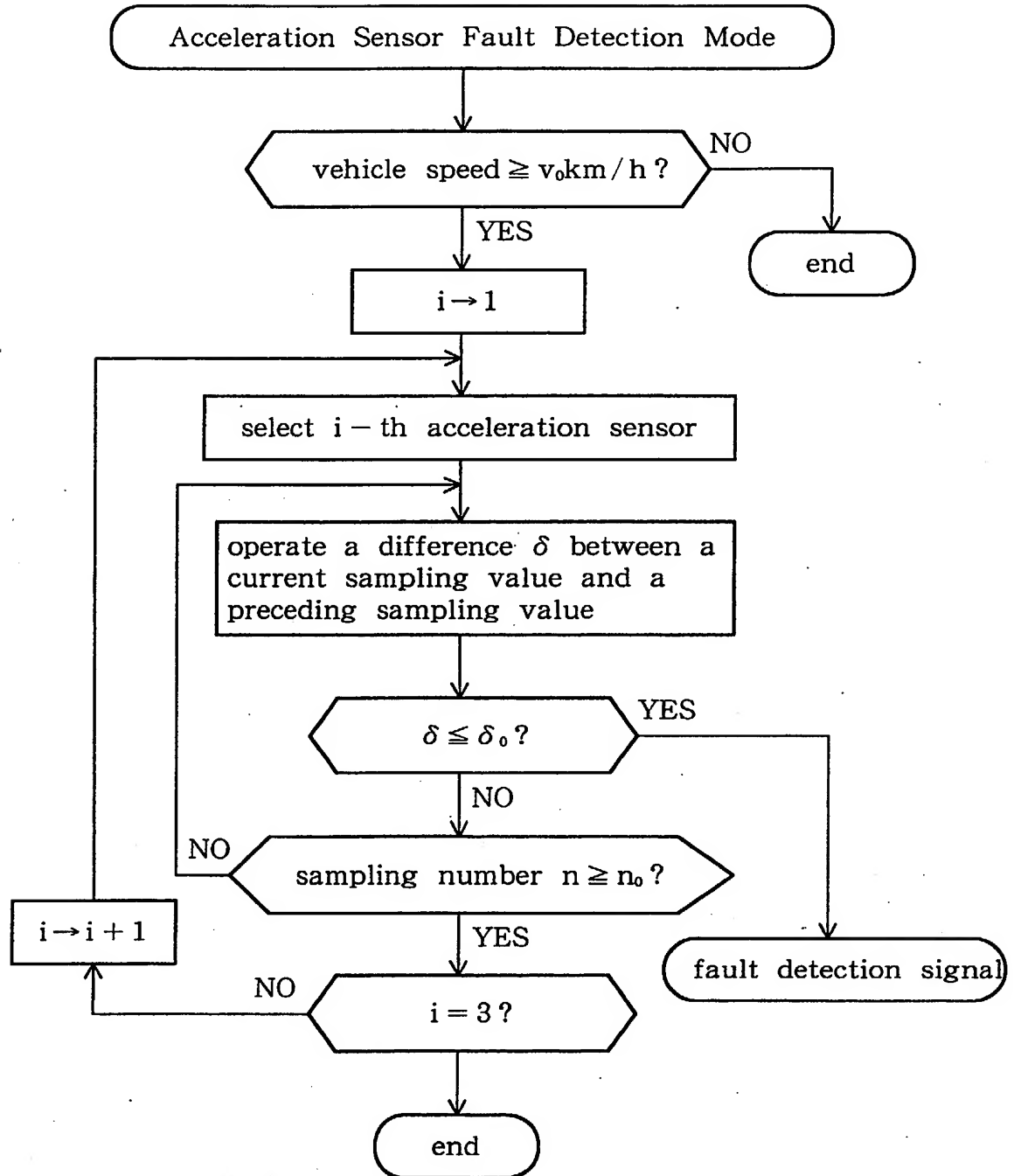


FIG.2

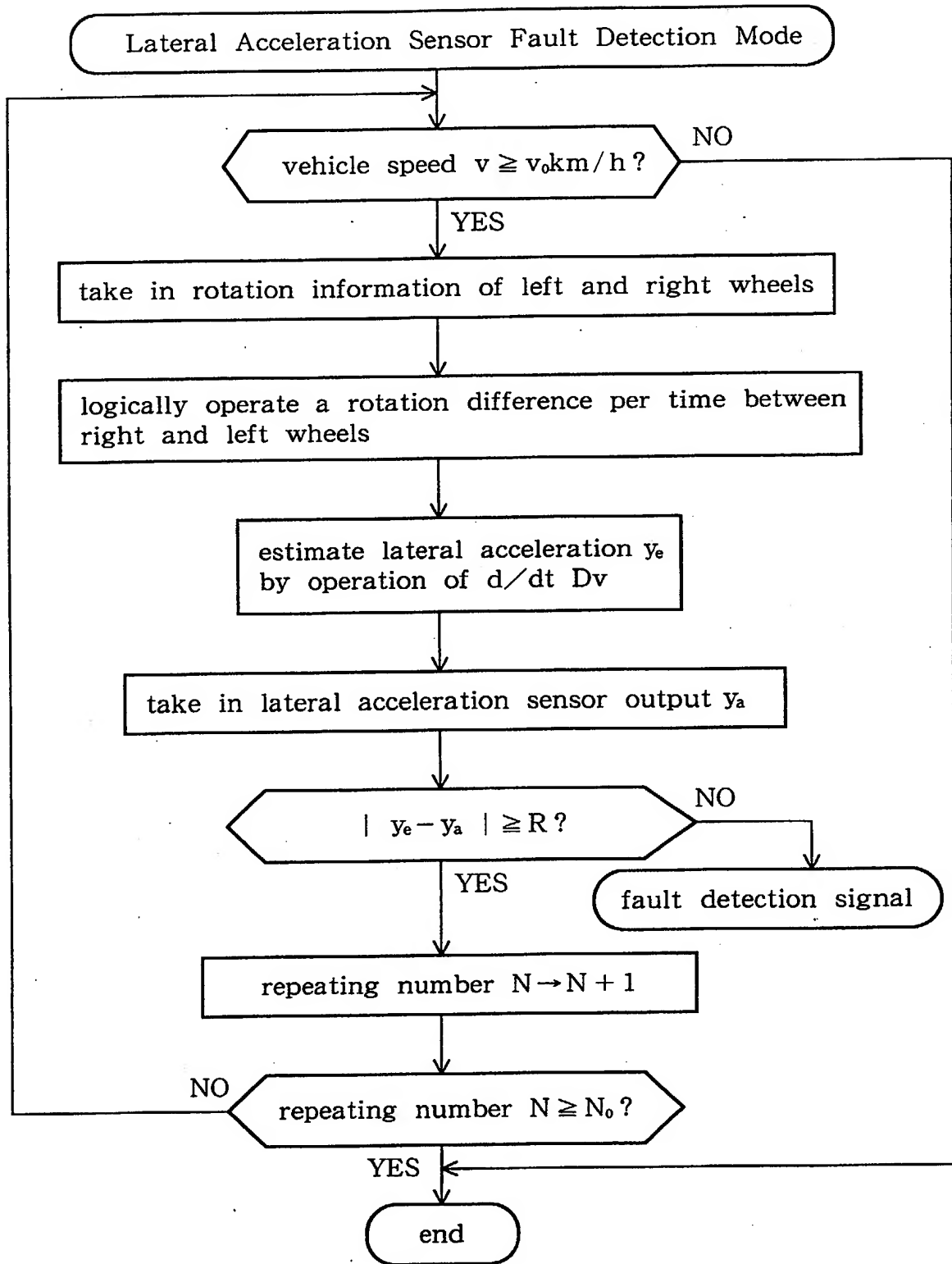


FIG.3

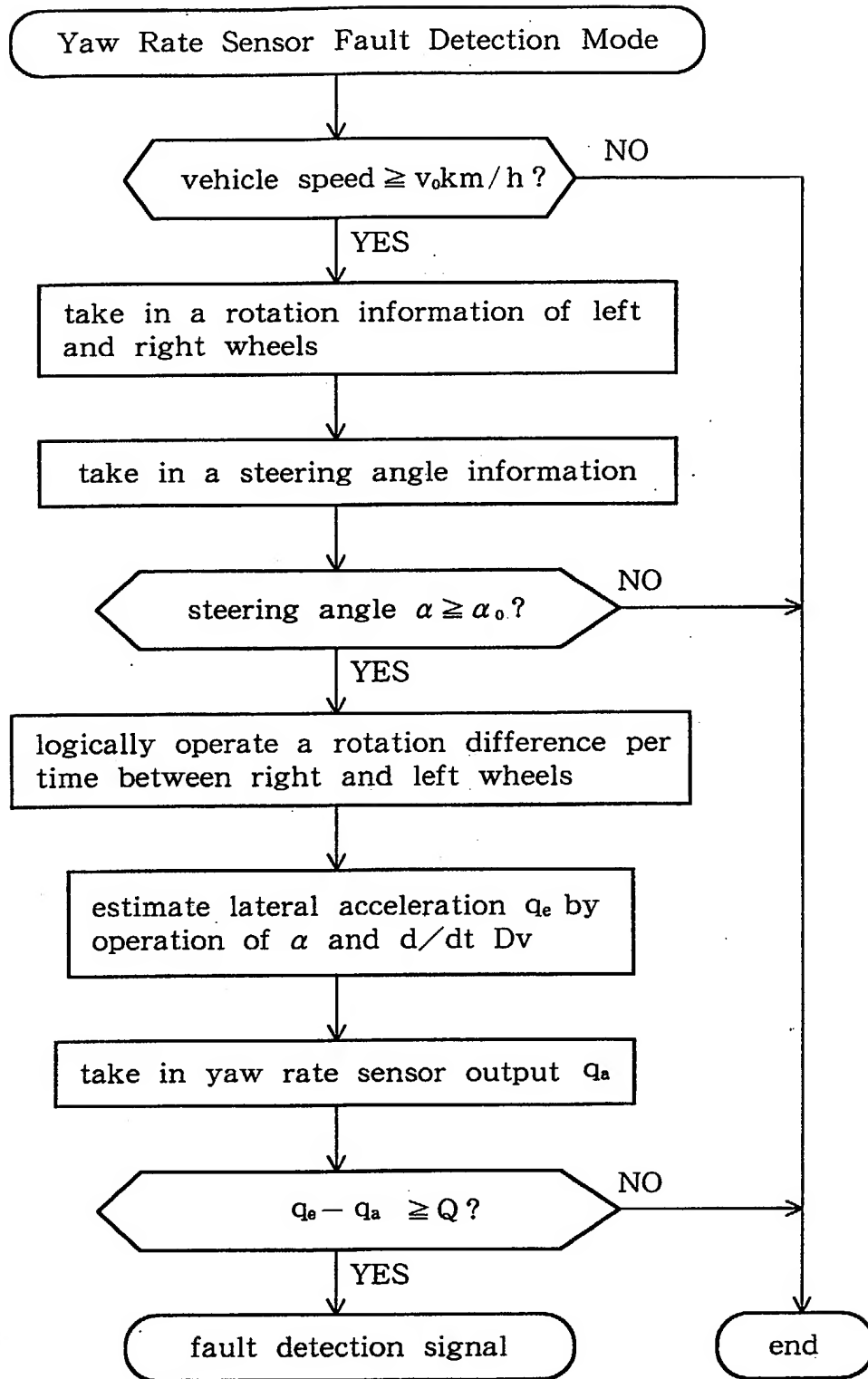


FIG.4

## SENSOR FAULT DETECTOR

5       The present invention relates to a fault detector for detecting a fault of  
an acceleration sensor, which is utilized in a vehicle stability control device  
(or vehicle attitude control device). Although the fault decision device of the  
present invention is developed such that it is to be assembled in a vehicle  
stability control device as a portion of an operation logic thereof, the fault  
10   detector can be utilized as a separate unit.

      The vehicle stability control (VSC) system controls a vehicle according  
to an acceleration information from an acceleration sensor for sensing  
acceleration in a vehicle running direction, that is, a forward or backward  
15   running direction, a lateral acceleration from an acceleration sensor for  
sensing acceleration in a lateral, that is, left or right, direction and a yaw  
rate sensor, all of which are mounted on the vehicle, a rotation information  
of respective wheels and a steering angle information, etc., such that, when  
an acceleration of the vehicle in a direction, which is inconsistent with a  
20   steering direction intended by a driver of the vehicle, is increased beyond a  
preset limit value, a braking force in a portion of the wheels is  
automatically generated. For example, when acceleration in a right forward  
direction is increased and yaw rate in counterclockwise direction is  
increased beyond a preset condition, the VSC system automatically  
25   generates a braking force in a rear left wheel such that an original attitude  
of the vehicle is restored before the state of the vehicle becomes  
uncontrollable by the driving operation of the driver.

As mentioned above, the acceleration sensors and the yaw rate sensor are utilized in the VSC system for detecting the state of the vehicle. Each of these acceleration sensors usually has a structure in which a movement of a weight of the acceleration sensor, which is supported by a plurality of springs, is physically detected. Therefore, if the weight of the acceleration sensor becomes impossible to move for some reason, it becomes impossible to precisely detect the state of the vehicle, so that the VSC system may perform an erroneous control.

Yaw rate is a rotational acceleration generated around a gravity center of the vehicle in a plane perpendicular to a moving direction of the vehicle. In this specification, the acceleration sensors in running direction and in lateral direction and the yaw rate sensor will be referred to as mere "acceleration sensor" totally.

Some conventional VSC system includes physical detection means for physically detecting the state in which the weight of the acceleration sensor becomes fixed. In such VSC system, which utilizes an output of such acceleration sensor, an erroneous operation of the acceleration sensor is detected according to an output of the detection means, which is indicative of the fixed state of the weight. Further, JP H04-110267A, JP H07-033037A and JP H07-196029A disclose techniques in which an abnormality of an acceleration sensor is detected by estimating acceleration generated in a vehicle on the basis of a change of vehicle speed and comparing the estimated acceleration with an output of the acceleration sensor mounted thereon. Further, JP H08-136572A discloses a technique related to a correction of an intermediate position of an acceleration sensor, in which an output value of the acceleration sensor mounted on a vehicle is corrected by estimating an output torque of an engine of the vehicle.

The conventional physical detector of a fault state of an acceleration sensor, which is caused by fixing of a weight thereof, can not detect the fault when a level of a detection signal of the acceleration sensor is low. That is, the fault detection sensitivity of the physical fault detector is low when acceleration applied to the acceleration sensor is small and, only when the acceleration applied to the acceleration sensor is larger, the fault detection becomes possible. In order to make a fault detection possible even when acceleration applied to the sensor is small, it is necessary to improve both the design preciseness of the physical detector and the machining preciseness thereof, causing the sensor device to be expensive.

Further, such physical detector of an acceleration sensor fault requires an increased size of hardware correspondingly. That is, the size of the physical detector becomes large. There is a possibility that the physical acceleration sensor fault detector itself becomes fault. Since a control device utilizing an output signal of such sensor is designed such that an operation of the physical detector becomes failsafe condition against a fault of the physical detector, there may be a case where the vehicle stability control device can not operate appropriately due to fault of the physical detector, even when the acceleration sensor operates normally.

According to a first aspect of the present invention, an acceleration sensor fault detector, which can be utilized together with any of an acceleration sensor in vehicle running direction, an acceleration sensor in lateral direction and a yaw rate sensor, comprises means (1) for sampling an output of the acceleration sensor periodically and means (2) for generating a fault detection signal (3) when a vehicle speed is equal to or higher than a predetermined value ( $v_0$  km/h) and a variation of the output of the

acceleration sensor sampled through a plurality (n) of sampling periods is equal to or smaller than a predetermined value ( $\delta_0$ ).

The symbols in parentheses correspond to reference symbols used in the accompanying drawings showing an embodiment of the present invention to be  
5 described later. It should be noted that these symbols are attached in order to facilitate an understanding of the present construction and are not meant to limit the present invention to the shown embodiment. This is also true in the following description.

The present invention provides a sensor fault detector capable of detecting an abnormality of an acceleration sensor on the side of a vehicle stability control device  
10 utilizing an output of the acceleration sensor, without requiring any specific detection means.

The sensor fault detector is capable of being embodied by changing software without requiring any hardware on the side of an acceleration sensor as well as the side of a vehicle stability control device.

15 The present invention provides a vehicle stability control device, which can utilize an inexpensive sensor and can be economized totally. A high quality, inexpensive vehicle stability control device is provided utilizing a physical acceleration fault detector, which can be designed such that the detector roughly detects a fault of an acceleration sensor when a level of a detection signal of the physical detector is  
20 high.

The predetermined value ( $v_0$ ) of vehicle speed is a speed of a vehicle practically running. The value ( $v_0$ ) is preferably set to, for example, 2km/h to 20km/h. The predetermined variation value ( $\delta$ ) is as small as a discriminatory sensitivity of the

acceleration sensor. The detection signal generated by the acceleration sensor is sampled by an interface circuit provided in an input of the logical operation circuit (2) and taken in the logical operation circuit (2) as a digital signal. Since a sampling period of a practical sampling circuit is in a range from one several tenth seconds to one  
5 several thousandth seconds, the number  $n$  of sampling periods during a short time from a time instance at which the logical operation circuit sets an acceleration sensor fault detection mode to a time instance at which the fault detection is performed may be set to several tens to several thousands.

When the vehicle is running practically and the sampling output of the interface  
10 circuit over a plurality ( $n$ ) of sampling periods does not indicate an identifiable variation, the acceleration sensor fault detector decides that the weight of the acceleration sensor is fixed. It is most reasonable to detect a variation of the sampling output by comparing a current sampling output obtained in a certain sampling period with a sampling output obtained in a sampling period immediately preceding the certain  
15 sampling period and repeating the comparison every sampling period. However, the variation of the sampling output may be detected every time corresponding to  $n$  sampling periods or every time corresponding to a plurality number of sampling periods smaller than  $n$ .

Due to vibrations, an output of an acceleration sensor of a running vehicle,  
20 which is displayed on a time axis of an oscilloscope screen, always shows a small change. However, when the weight of the acceleration sensor is fixed, such small change disappears completely. The present acceleration sensor fault detector detects such state as an occurrence of fault and generates a fault detection signal. Therefore,

the construction of the present acceleration sensor fault detector is simple compared with the conventional detector, which executes the estimation operation of acceleration. Further, the time required to detect an acceleration sensor fault is short in the present acceleration sensor fault detector and the possibility of fault of the fault detection  
5 device itself is very small.

According to a second aspect of the present invention, the acceleration sensor fault detector is featured by including means (2) for estimating a lateral acceleration of a vehicle by taking in a rotation information of right and left wheels and time-differentiating a difference in rotation speed between the right and left wheels and  
10 means for generating a fault detection signal (3) when there is a difference larger than a predetermined value between the lateral acceleration estimated by the means (2) and a detection output of the lateral acceleration sensor

The acceleration sensor fault detector estimates a lateral component of an acceleration of the vehicle from the rotation information of the right and left wheels  
15 and decides that the lateral acceleration sensor does not operating correctly when the output of the lateral acceleration sensor is within an approximate value with respect to the estimated lateral acceleration component of the acceleration.

According to a third aspect of the present invention, the acceleration sensor fault detector is featured by comprising means for estimating a yaw rate of a vehicle on the  
20 basis of a steering angle of a vehicle and a time-differentiated value of a difference in rotation speed between the right and \_\_\_\_\_

left wheels when the steering angle is a predetermined value  $\alpha_0$  or larger and means for comparing the estimated yaw rate with an output of a yaw rate sensor and generating a fault detection signal when there is a predetermined error or more therebetween.

5        When a driver of the running vehicle steers a steering wheel, the acceleration sensor fault detector of the present invention estimates the yaw rate on the basis of the steering angle and the rotation information of the right and left wheels of the vehicle and, when the estimated yaw rate is not close to the output of the yaw rate sensor, decides that the yaw rate sensor is not operating correctly.

10

Embodiments of the present invention will be described with reference to the drawings, in which:

FIG. 1 is a block diagram of an acceleration sensor fault detector according to the present invention;

15        FIG. 2 is a main control flowchart according to a first embodiment of the present invention;

FIG. 3 is a main control flowchart according to a second embodiment of the present invention; and

20        FIG. 4 is a main control flowchart according to a third embodiment of the present invention.

An acceleration sensor fault detector is embodied in a vehicle stability control (VSC) device shown in FIG. 1 as a software of a logical operation circuit of the vehicle stability control device.

25        The acceleration sensor fault detector comprises an acceleration sensor 11 mounted on a vehicle for sensing acceleration in a moving direction of the vehicle, an acceleration sensor 12 mounted on the vehicle for

sensing an acceleration of the vehicle in a direction perpendicular to the moving direction of the vehicle and a yaw rate sensor 13 mounted on the vehicle for sensing a yaw rate of the vehicle. Outputs of these three acceleration sensors are connected to an interface circuit 1 and sampled  
5 therein, respectively. A sampling period is 1/100 seconds corresponding to a sampling frequency of 100Hz. Sampled detection signals are supplied to a logical operation circuit 2.

The logical operation circuit 2 is connected to another interface circuit 5 to which a vehicle speed information indicative of a rotation of an output  
10 shaft of a change gear of the vehicle, a wheel rotation information obtained from respective front and rear wheels, a steering angle information indicative of a rotation angle of a steering wheel and, etc., are inputted. These information are sampled in the interface circuit 5 and supplied to the operation circuit 2.

15 The logical operation circuit 2 constitutes an information input portion of a control circuit 4 of the vehicle stability control device. The logical operation circuit 2 and the control circuit 4 of the vehicle stability control device are constructed as a single circuit, practically. The control circuit 4 operates these input information to set a body model of the vehicle in a  
20 running state and, when an acceleration vector produced in the vehicle body model is increased beyond a predetermined limit, decides a possibility of turning sideways of the vehicle. According to the decision, the control circuit 4 controls the vehicle such that a braking force is applied to a portion of the wheels in a direction in which the increase of the acceleration vector is  
25 suppressed. That is, an output of the control circuit 4 is sent to a brake system of the vehicle through an interface circuit 6.

The feature of the present invention resides in a fault detection of the

acceleration sensor connected to the interface 1. That is, when there is a fault in the acceleration sensor, the fault is detected on the basis of an acceleration output value of the acceleration sensor, upon which a fault detection signal 3 is produced.

5       A fault detection logic according to a first embodiment of the present invention will be described with reference to FIG. 2, which is a main flowchart of the fault detection logic. In FIG. 2, the logical operation circuit 2 is automatically and periodically set in a fault detection mode for a short time. In the fault detection mode, when a vehicle speed is equal to or higher  
10   than a value  $v_0$ , which is, in this example, 5km/h, the logical operation circuit 2 determines whether an output of the  $i$ -th acceleration sensor is equal to or smaller than a predetermined value  $\delta_0$ . This is repeated for all of the acceleration sensors by changing  $i$  sequentially. In this example,  $i$  is 1 to 3, so that the output signals of the three acceleration sensors are checked sequentially.

15       An output of an acceleration sensor of a running vehicle always shows a small change caused by vibration of the vehicle. However, when the weight of the acceleration sensor is fixed, such small change disappears completely. When such small change can not be detected by the acceleration sensor, the logical operation circuit 2 sends the fault detection signal 3 to the control  
20   circuit 4, upon which the control circuit 4 executes a failsafe operation.

      The practical acceleration sensor fault detector of the present invention was constructed such that the sampling period of the acceleration sensor output is 0.01 second and, when the vehicle speed is 5km/h or higher, the fault detection signal is produced when a state in which a difference  
25   between a sample value in a current sampling period and a sample value in a preceding sampling period is 0.01G or less continues for 5 seconds. In a running test of a vehicle on which this acceleration sensor fault detector is

mounted, very good test result was obtained. That is, when the running test was performed by intentionally providing a fixing state of the weight of the acceleration sensor, the generation of the fault corresponded to the generation of the fault detection signal very precisely. Although the construction of the acceleration sensor fault detector of the present invention is simple, the practical effect thereof is substantial.

A second invention of the present invention has the same construction as that shown in FIG. 1. FIG. 3 is a main portion of a fault detection logic according to a second embodiment of the second invention. In FIG. 3, the logical operation circuit 2, which, in the fault detection mode, detects a fault of the lateral acceleration sensor, takes in the rotation information of the right and left wheels when the vehicle running speed is equal to or higher than the practical running speed  $v_0$ , time-differentiates a rotation difference  $D$  (rotation speed difference) per time between the right and left wheels and operates an estimated lateral component  $y_e$  of acceleration of the vehicle. The logical operation circuit 2 compares the estimated lateral component with an output value of the lateral acceleration sensor 12 and, when there is a difference exceeding a preset value  $R$  therebetween, decides an output abnormality of the lateral acceleration sensor 12 and sends a fault detection signal. When the difference between the estimated lateral component and the output value of the lateral acceleration sensor is smaller than the preset value  $R$ , this operation is repeated  $N_0$  times for confirmation purpose.

The lateral component  $y_e$  of the acceleration of the vehicle is obtained on the basis of the rotation speed difference  $D$  between the right and left wheels and the vehicle speed  $v$ . That is, the lateral component  $y$  of the vehicle speed is represented by the following equation:

$$y = v \cdot \sin \theta$$

where  $\theta$  is an angle of the vehicle speed vector with respect to the vehicle running direction.

Assuming that a distance between the right and left front wheels is  $L$ ,  $\theta = D/L$ . Therefore, the above equation becomes as follow:

5 
$$y = v (D/L)$$

Since the distance  $L$  is a constant determined by the kind of vehicle and can be represented by  $L = 1/k$  where  $k$  is a proportional constant, the above equation can be rewritten as follow:

$$y = k \cdot Dv$$

10 Since a time-differentiated value of this is the lateral component  $y_e$  of the acceleration, the above equation is rewritten as follow:

$$y_e = k \cdot (d/dt)Dv$$

The practical acceleration sensor fault detector was constructed such that the fault detection signal is produced under conditions that the vehicle  
 15 speed is equal to or higher than the predetermined value (15km/h), the operated lateral component  $y_e$  of the acceleration is equal to or larger than a predetermined value (0.25G) and a state where a difference between the operated lateral component and the detection output of the yaw rate sensor is equal to or larger than 0.1G continues over the repetitive sampling  
 20 periods equal to or longer than a predetermined time (1 second).

A block diagram of a third invention is the same as that shown in FIG.

1. FIG. 4 is a main portion of a fault detection logic according to a second embodiment of the second invention. In FIG. 4, the logical operation circuit  
 2 in the fault detection mode for detecting a fault of the yaw rate sensor  
 25 takes in the rotation information of the right and left wheels and the steering information  $\alpha$  when the vehicle running speed  $v_0$  is abnormal, operates a yaw rate  $q_e$  of the vehicle on the basis of the steering information

$\alpha$  and a time-differentiated value of a difference of rotation per time between the right and left wheels. The logical operation circuit 2 compares the estimated yaw rate  $q_e$  with an output  $q_s$  of the yaw rate sensor and, when a difference therebetween exceeds a preset value  $Q$ , generates a fault  
 5 detection signal.

The yaw rate  $q_e$  is obtained by the equation  $q_e = (\text{rotation speed difference } D \text{ between right and left front wheels})/(\text{front wheel tread})$ .

The practical acceleration sensor fault detector was constructed such that the fault detection is executed under conditions that the vehicle speed  
 10 is equal to or higher than a predetermined value (5km/h) and the operated yaw rate is equal to or larger than a predetermined value (15 degree/sec) or the rotation angle of the steering wheel is equal to or larger than a predetermined value (80 degree). According to the test conducted by the present inventors, it has been found that the decision limits may be very  
 15 rough. In this test, the acceleration sensor fault detector was constructed such that the fault detection is executed under the above mentioned conditions and, when signs of the output value of the yaw rate sensor and the operated yaw rate are the same, the yaw rate sensor is decided as normal and, when signs thereof are different, the fault detection signal is  
 20 generated. That is, in the practical acceleration sensor fault detector, the "difference equal to or larger than the predetermined value" may mean that signs of the output of the yaw rate sensor and the operated yaw rate are different.

According to the present invention, the abnormality of an acceleration  
 25 sensor can be decided with high sensitivity on the side, which utilizes an output of the acceleration sensor, without providing any special detection means on the acceleration sensor. Adding software of the control circuit,

with adding any hardware to neither the sensor side nor the control device side can embody the present invention. When the vehicle stability control device according to the present invention is used together with an acceleration sensor fault detector, which detects a fault physically, it is  
5 possible to design the detector such that it performs a rough fault detection when a level of the detection output is high. Therefore, it is possible to provide a high quality vehicle stability control device at low cost.

## CLAIMS

1. An acceleration sensor fault detector for detecting a fault of an acceleration sensor, comprising means for periodically sampling an output  
5 of said acceleration sensor and means for generating a fault detection signal under conditions that a vehicle speed is equal to or higher than a predetermined value and that a variation of the output of said acceleration sensor is equal to or smaller than a predetermined value for a plurality (n) of sampling periods.
- 10 2. An acceleration sensor fault detector for detecting a fault of a lateral acceleration sensor, comprising means for estimating a lateral acceleration of a vehicle from a time-differentiated value of a difference in rotation speed between right and left wheels of said vehicle by operating a rotation  
15 information of said right and left wheels and means for comparing the estimated lateral acceleration with an output of a lateral acceleration sensor and generating a fault detection signal when there is a difference therebetween, which is equal to or larger than a predetermined value.
- 20 3. An acceleration sensor fault detector for detecting a fault of a yaw rate sensor, comprising means for estimating a yaw rate from a steering angle and a time-differentiated value of a difference in rotation speed between  
said right and left wheels when said steering angle is equal to or larger than a predetermined value  $\alpha_0$  and means for comparing the estimated yaw rate with an  
output of said yaw rate sensor and generating a fault detection signal when there is a  
difference therebetween, which is equal to or larger than a predetermined value.

4. An acceleration sensor fault detector substantially as hereinbefore described with reference to any of the examples shown in the accompanying drawings.



INVESTOR IN PEOPLE

Application No: GB 0116041.5  
Claims searched: 1

Examiner: Pierre Oliviere  
Date of search: 19 February 2002

## Patents Act 1977 Search Report under Section 17

### Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:  
UK Cl (Ed.T): G1N (NAHK, NACA)  
Int Cl (Ed.7): G01P (15/00, 15/03, 15/08, 15/13, 21/00); G01D (3/08)  
Other: Online: WPI, EPODOC, PAJ

### Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
X	US 4337516 (MURPHY)	1
X	JP 100048251 A (HINO) Abstract	1
X	JP 040313062 A (HONDA) Abstract	1
X	JP 630132171 A (NIPPON DENSO) Abstract and figure 2	1

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

**PUB-NO:** GB002368400A  
**DOCUMENT-IDENTIFIER:** GB 2368400 A  
**TITLE:** Acceleration sensor fault  
detector  
**PUBN-DATE:** May 1, 2002

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**APPL-NO:** GB00116041  
**APPL-DATE:** June 29, 2001

**PRIORITY-DATA:** JP2000206756A (July 7, 2000)

**INT-CL (IPC):** G01P021/00

**EUR-CL (EPC):** G01P015/18 , G01P021/00